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# New Findings in Texture Development and Phase Transformation in Shock Pre-Strained Zirconium Could Shed Light on Models for Shock-Induced Phase Transformations

A detailed understanding of the stress-induced texture evolution and phase transformations that occur during shock loading of weapons materials is central to understanding and accurately modeling the underlying implosion physics in nuclear weapons. Transitions of importance include solid-solid phase transformations, dissociation transitions, and shock-induced melting. Phase transitions in weapons materials, especially if associated with a large volumetric change, can profoundly affect material states and constitutive, damage, and fracture properties during implosion. Researchers from MST Division recently examined shock-induced changes in a sample of high-purity zirconium using neutron diffraction on the High Intensity Powder Diffractometer (HIPD). Zirconium exhibits a subset of the extremely complex dynamics and phase-stability behavior exhibited by materials relevant to the Stockpile Stewardship Program, the Stockpile Life Extension Program (a Defense Program thrust to extend the service life of existing weapon systems)**,** and core elements of the Nuclear Weapons Technology Program. The goals of the present studies on zirconium are to develop models of the equation of state and strength of weapons materials and to improve our understanding of the fundamental physics and materials science of nuclear weapons.

The recent experiment on HIPD quantified the texture evolution and phase transformations in zirconium before and after the sample had been *shock pre-strained* below and above the $\alpha-\omega$ shock-induced phase transition (i.e., the sample was subjected to a high-pressure shock at 65 and 80 kbar with the 80-mm gas-gun launcher at MST-8 and then *soft* recovered)**.** The shocked sample was then recovered *intact* for a metallurgical evaluation of the effects of the shock pre-straining procedure on the microstructure of the sample. Shock pre-straining a sample facilitates the systematic quantification of the evolution of texture caused by the mechanical action of the procedure. Because of the difficulties involved in studying the physical properties of materials during a shock, shock-recovery experiments like the one performed on the HIPD offer researchers an opportunity to study the mechanisms involved in the generation and storage of defects in materials subjected to impulse loading histories.

The $\alpha-\omega$ shock-induced phase transition in zirconium was quantified using velocity interferometric (VISAR) wave-profile measurements in DX Division to occur at ~ 74 kbar. Obtaining a bulk measurement of the volume fraction and lattice parameters of the metastable $\omega$ phase retained in the *soft* recovered sample following shock pre-straining above 74 kbar was critical to the success of this experiment. X-ray measurements can only provide surface information, which is almost certainly not representative of the bulk, leaving neutron diffraction as the *sole* experimental method with access to the quantitative volume-fraction information that we are seeking to support validation of phase equilibrium modeling. The combination of multiple detector banks at high angle and high neutron intensity from the spallation neutron source at LANSCE make the HIPD an ideal instrument on which to perform these measurements.

The researchers measured the texture of the zirconium sample as a control to quantify the starting orientation of the material before it was shock pre-strained. The texture of the starting material exhibits strong basal texture (Fig. 1). After the sample was shock pre-strained, analysis of the crystallographic texture below the phase-transition pressure showed essentially no change (Fig. 2). However, shock pre-straining above the phase transition decreased the basal fiber texture significantly (Fig. 3). Rietveld analysis of the neutron-diffraction data obtained on HIPD identifies that there is a 39% metastable retained ω phase in the zirconium sample shocked at 80 kbar, whereas the sample that was shock pre-strained below the α–ω phase transition displayed no evidence of a retained high-pressure ω phase. The substantial amount of retained metastable ω phase is consistent with wave-profile results from DX-1, which note the absence of a rarefaction shock upon shock release when the sample was loaded above the phase-transition pressure. The retained metastable high-pressure ω phase also exhibited a strong basal component to its texture in the sample shocked above the phase-transition pressure (Fig. 4). This observation is consistent with the strong orientation relationship between the α-ω phase transition, which accommodates the c-axis collapse during the phase transition. The initial results of this study will be used to quantify the texture evolution in zirconium as a function of imposed shock peak pressure and will contribute to fundamental modeling studies of the kinetics of the α-ω phase transition.

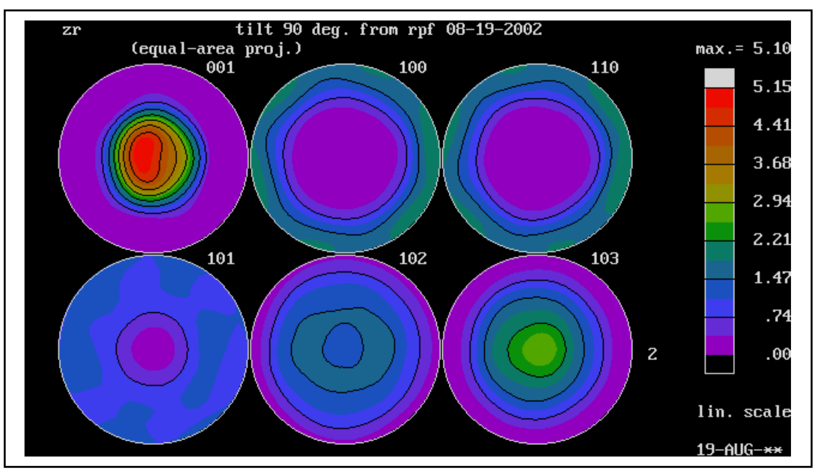


Fig. 1. Strong basal texture in the annealed zirconium.

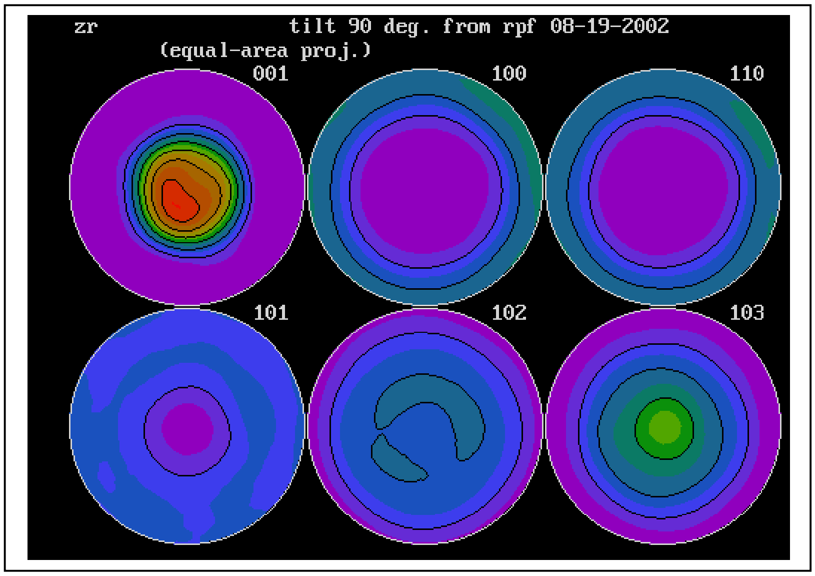


Fig. 2. Texture of zirconium following shock pre-straining below the α–ω phase transition (at ~ 6.5 GPa).

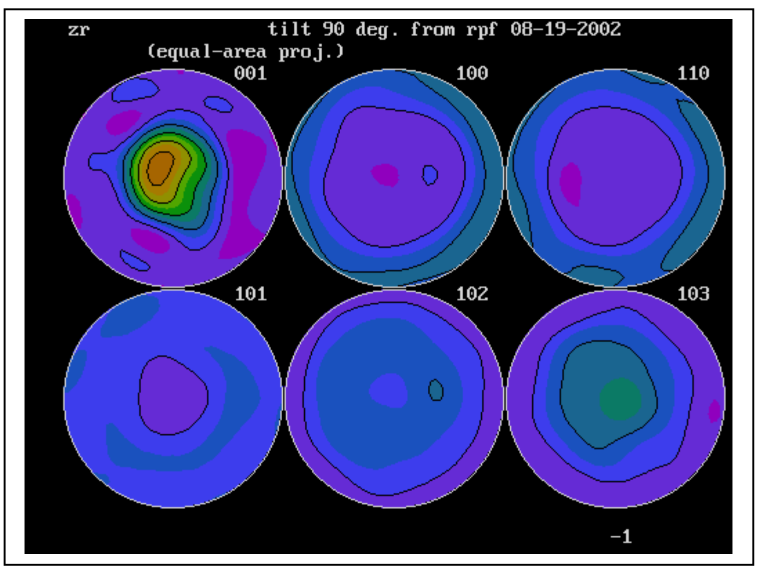


Fig. 3. Texture of zirconium following shock pre-straining above the α–ω phase transition (at 8.0 GPa).

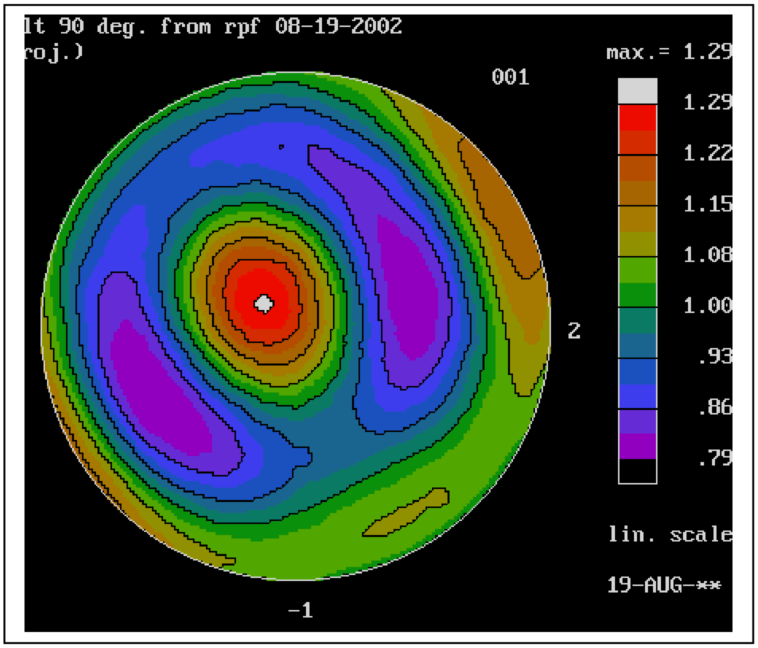


Fig. 4. Texture of the retained ω phase in the zirconium shock pre-strained to 8.0 GPa.

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